

# looking ahead

.... A monthly report by the National Planning Association on forward-looking policy planning and research—announced, underway, and completed—of importance to the nation's future

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*the people of NPA*

### An Appraisal

## Prospective Nuclear Power Costs

by Sam J. Van Hyning

*Mr. Van Hyning is a member of the NPA Project on the Productive Uses of Nuclear Energy and co-author with Michael Sapir of "The Outlook for Nuclear Power in Japan."*

THE NPA PROJECT on the Productive Uses of Nuclear Energy has recently published "The Outlook for Nuclear Power in Japan" and has underway the following additional country case studies: Brazil, India, Israel, Italy, and Pakistan. The prospects for nuclear power costs over a wide range of reactor sizes--from quite small to very large plants—are a critical element in an appraisal of the possible economic impact of nuclear power. It is the purpose of this article to indicate how this problem of nuclear power costs has been approached in the work of NPA's Project, and to note some of the available expert opinion on prospective nuclear power costs.

The basis for the economic analysis, in each of the country case studies, of the possible effects of nuclear power consist of two different nuclear power cost concepts. The first concept involves the "competitive threshold" which nuclear power must cross in order to operate at cost parity with conventional power plants. The second concept involves what may be termed the "ultimate" cost prospect for nuclear power.

It cannot be too strongly emphasized that prospective nuclear power costs and their timing are necessarily highly speculative. "The Outlook for Nuclear Power in Japan" indicates two major areas of technological uncertainty (and these apply equally to an appraisal of nuclear power costs for any area) affecting nuclear power costs. The first is the lack of any substantial operating experience with nuclear power reactors. The second is a similar lack of experience with the fabrication and reprocessing of nuclear fuels for such plants.

The economic appraisal contained in "The Outlook for Nuclear Power in Japan" is concerned exclusively with large plants--100 megawatts and above. What are the prospects for the achievement

### Planning

- **"Foreign Misconception"**—The American economy is unplanned.
- **"The Facts"**—There is more planning going on in the United States than in any other country, including the Soviet Union. Financial and economic planning is one of the main preoccupations of Government. Taxes, tariffs, national debt, credit policies, etc. are considered in view of their impact over the economy. Planning is one of the main functions of most corporations, large and small. Individuals plan their economic activities more, probably, than they do in most other nations. The American economy is planned, but differently. It is not collectivistic planning, but planning for freedom."

*Excerpt from a lecture on American Capitalism by Massimo Salvadori, professor of history, Smith College and Bennington College. This lecture, President Eisenhower said, "contains some of the best ideas I have seen on the subject (of making American objectives clear to people in other countries) ... I am going to circulate them as widely as I can."*



of competitive nuclear power in this size range, for it is certainly true that the possible economic effects of nuclear power generation are of significance for planning purposes only if the stated nuclear power costs assumptions are valid? What does the concept of the competitive threshold for a large plant mean and what is meant by the concept of ultimate costs?

For the first of these concepts, the Japan study concludes that the competitive threshold which nuclear power must cross to achieve cost parity with a conventional thermal power plant would, in 1965, be about 10 mills/KWH. This definition of the Japanese competitive threshold rests on two broad conclusions concerning Japan's conventional energy supply position. The first of these general judgments is that production costs in the Japanese coal industry cannot be substantially reduced from present levels. The second conclusion is that construction costs for hydroelectric plants will rise steadily from present levels.

In addition to reflecting the conclusions summarized above, the 10 mill/KWH threshold concept for nuclear power rests on the following assumptions:

- 1) Stability in the price of imported oil.
- 2) Ending by the Japanese Government of present practices which discriminate against imported fuel oil and protect the Japanese coal industry.
- 3) Technological advances in the Japanese electric power equipment industry which will result in higher thermal efficiencies in conventional power plants.

The concept of low-cost nuclear power differs from the threshold concept. The definition of low-cost nuclear power reflects a judgment concerning what may be termed the ultimate cost prospects for nuclear power. These prospects would differ from country to country only as a function of certain nontechnical questions such as rates of interest, rates of plant utilization, insurance costs, and tax rates. For purposes of the economic analysis in the Japanese study, it was assumed that nuclear power could be generated, possibly by 1975, and in any event not far beyond that date, at the 5 mill/KWH level.

CAN 10 MILL/KWH nuclear power be achieved in Japan by 1965? An unqualified affirmative answer to this question cannot be given, but there is responsible and expert testimony which is encouraging. It should be borne in mind in relation to timing (nuclear power production by 1965) that allowance must be made for the

relatively long time cycle involved in reactor design and construction. In the case of Japan, this would probably mean a commitment on their part no later than 1960 to a specific reactor system.

The expert testimony referred to above concerns the Pressurized Water Reactor (PWR) in the so-called "experimental" program of the United States Atomic Energy Commission, and the Calder Hall type of plant in the United Kingdom's dual-purpose (power and plutonium) program. The PWR plant is under construction near Pittsburgh in Beaver County, and is scheduled for completion in 1957. The British plan to begin electric power production at Calder Hall later this year.

Rear Adm. H. G. Rickover, Chief, Naval Reactors Branch, Division of Reactor Development, U. S. Atomic Energy Commission, in December 1955 presented cost estimates for the PWR. Looking ahead about ten years, Admiral Rickover's presentation of estimated costs may be summarized as follows:

Gross generating costs might amount to about 13 mills/KWH or slightly less. This figure rests upon the following assumptions: equipment procurement based on proven plant design, reactor core life double that of early operation, and very substantial reductions in operating and maintenance costs.

Sir Christopher Hinton, director, Industrial Group, British Atomic Energy Authority, in a speech delivered in Tokyo, Japan in May 1956, estimated power costs in a more advanced Calder Hall type of plant at "rather less than one penny per unit" (presumably about 9-10 mills/KWH). Hinton was not explicit concerning timing but it seems a reasonable inference that he referred to a plant which might operate in Britain in the early 1960's. It should be further noted that Hinton's estimate did not subsume a "plutonium credit." Hinton's comment on this method of accounting, which is commonly encountered in nuclear cost literature, is worth noting: "The Calder Hall reactors were not built simply for power production; they were built as dual purpose reactors for power production and for the production of plutonium for defense purposes. I think it would be misleading to attempt to quote any cost of power generation from such dual purpose machines even if this was permissible."

These estimates for power costs in early plants (in operation by 1965) indicate a cost range roughly of 9-13 mills/KWH. For non-technical reasons, such data for the United States and the United Kingdom cannot be super-

imposed on a third country such as Japan. However, they are relevant in judging the possibility of producing 10 mill nuclear power in Japan by 1965. The data support the judgment that nuclear power at this level of costs is a reasonable possibility.

Two U.S. survey teams have made assessments of the longer-range prospects of "ultimate" nuclear power costs, and these were summarized as follows in "The Outlook for Nuclear Power in Japan":

The United States Atomic Energy Commission in 1954 expressed the following judgment concerning the achievement within 20 years of nuclear power generating costs in the 4 to 7 mill range. "Achieving such cost levels is not certain at this stage in development, but the probability of success is good."

The primary basis for the Commission's cost range was Project Dynamo, a classified study, commissioned by AEC and done by the Massachusetts Institute of Technology in 1953. The summary results of the study were declassified in 1955 and show costs ranging from just under 4 mills to a little less than 7 mills on assumptions of private financing, at a rate of 15 percent for fixed charges, and an 80 percent plant factor.

More recently, estimates have been prepared by a group of U.S. private and public experts convened at the request of "The Panel on the Impact of the Peaceful Uses of Atomic Energy." The data were developed on a range basis reflecting what are termed "optimistic" and "pessimistic" forecasts. The "optimism" and "pessimism" refer to an assumed cost range for 1960, and also to the pace of development during the period 1960-80. The cost data set forth relate to major cost components and these are not brought together to reflect estimated total generating costs. Using assumptions identical with Project Dynamo for the annual rate (15 percent) of fixed charges and an 80 percent plant factor, we infer a cost range for 1980 from slightly below 5 mills/KWH to just under 6 mills/KWH.

The results of the two surveys can be reasonably construed as indicating that the prospects for low-cost nuclear power are good. The probability that low-cost nuclear power will be achieved is no more than an economist's interpretation of what he believes a substantial number of nuclear experts have said and are saying. In essence, the interpretation is as follows: The "optimists" exceed the "pessimists" concerning the prospects for achieving low-cost nuclear power, and "optimism" and "pessimism" relate mainly to the question of timing rather than to that of feasibility.

This question of timing is not unrelated to the variety of feasible reactor systems. Dr. Alvin M. Weinberg in his Geneva Conference

paper indicated the possibility of 900 reactors, and while he also indicated that most of these would not be practicable he went on to say:

Even so, there are probably at least 100 combinations which are not obviously unfeasible. The central issue in reactor development is to trace out of this welter of possibilities the dozen or so which are most likely to succeed.

This situation poses both an economic problem and an economic challenge. The problem arises in that the proving out of any reactor system is very expensive. W. Kenneth Davis in his Geneva Conference paper roughly estimated the net cost of carrying one type of reactor through the experiment and prototype (large plant) stages at \$110 million. The challenge exists in that the variety of feasible reactor types enhances the prospects for achieving low-cost power. Only the United States, among the Western powers, possesses the resources required to mount an intensive effort to evaluate what the experts indicate as being technically feasible systems.

THE NATURE of the challenge and the magnitude of the effort involved are further extended when the question of reactor size is considered. The cost estimates and assumptions discussed earlier have been concerned with large plants only—100 MW and larger. It is the plants in this size range which are of the greatest economic interest in the case of an industrialized country like Japan with a well-developed electric utility industry.

Other country case studies being conducted by the research staff and consultants to the NPA Project on the Productive Uses of Nuclear Energy are sufficiently well advanced to have demonstrated a substantial interest in the development of nuclear power plants ranging down in size to 1,000 KW or even smaller. Brazil and India are particular cases in point. There is a substantial and growing demand in each of those countries for power which today can best be met by small diesel plants which frequently produce at costs in excess of 30 mills/KWH.

In terms both of nuclear technology (economies of scale in larger plants) and the economic requirements of the United States, there has been a concentration of interest, though not an exclusive concern, with large plants. The so-called "second round demonstration program" of AEC (the 1955 AEC program inviting proposals in the 5,000-40,000 KW size range) is a case in point. The name of the program is suggestive of the relatively lesser interest in this country in small plants.

(continued)

However, there is one estimate which is unique in the entire field of nuclear power cost estimates. The Argonne National Laboratory has built and operated a small reactor producing power at about the 2,000 KW level. Cost estimates based on this experiment are set at about 34 mills/KWH. Dr. H. J. Bhabha, President of the Geneva Conference, singled out this experiment in his address concluding the Conference as a major highlight of the more than 1,000 papers prepared for the Conference:

The capital and operating costs of an actual power reactor in the United States with an installed capacity of about 2000 kilowatts were given. The cost of power from this small plant worked out at between 30 and 35 mills per kilowatt hour, which is less than double the cost of power produced by coal plants of the same size. It appears that there are many parts of the world where power would be acceptable at this price and small package power plants of this type may have wide-spread uses, especially in underdeveloped areas.

Bhabha's enthusiasm probably needs to be somewhat tempered in the light of the non-technical assumption concerning plant utilization: the 80 percent plant factor assumed would certainly be far in excess of usual experience with a plant of this size—reduction by half would be a more reasonable expectation. In addition, the highly enriched fuel used in this plant is not available for export under present U. S. policy.

Dr. W. H. Zinn's appraisal of the significance of the experiment would seem to place it in better perspective:

In conclusion, I would like to say that these power costs are less than a factor of 2 greater than the cost of power from a coal station of comparable size . . . We are greatly encouraged to find that a small plant has actually been constructed for which the power cost begins to approach a useful value.

Prospects in the size range 2,000-100,000 KW have not been touched on although a number of paper studies exist. This is in effect the problem of assessment of economies of scale in the field of nuclear power. The problem has been treated within the context of individual reactor systems but there is no generalized survey of the problem. This is a problem for the nuclear technicians rather than one which the economists can resolve.

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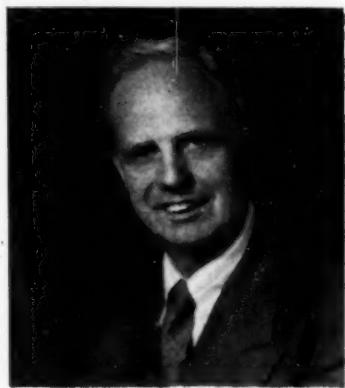
*The views expressed are the author's and should not necessarily be considered as those of the NPA Project on the Productive Uses of Nuclear Energy.*

## —*the people of NPA*—

Clarence

E.

Pickett



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Clarence E. Pickett, NPA trustee and executive secretary emeritus of the American Friends Service Committee, grew up in a Quaker farming area where an atmosphere of strong community affection and responsibility shaped his character. He received his BA from Penn College in Iowa and a BD degree from Hartford Theological Seminary, experiencing there, "a delightful sense of an expanding world." After several years as a Quaker minister and a year of graduate work at Harvard University, Mr. Pickett taught Biblical literature at Earlham College in Richmond, Indiana from 1923 until he accepted the post of executive secretary to the American Friends Service Committee in 1929. During the 1930's, he served in the Department of Interior's Division of Subsistence Homesteads; as consultant in the Resettlement Administration and the Farm Security Administration; and later as director of the U. S. Committee for the Care of European Children. In 1952, Mr. Pickett was appointed to President Truman's Commission on Immigration and Naturalization. A member of the six-man international Quaker team at the United Nations since 1950, Mr. Pickett has found that groups of private citizens may possess a spiritual objectivity helpful to officials in devising wise policy on international issues. "Often one is surprised to find how much search there is for a religious answer to the issues at stake. As I see it, one of the chief functions of delegations such as ours is to discover, encourage, and unite such seeking on the part of official delegates....One hopes that this kind of combined effort of official and unofficial groups may in the long run bear fruit in terms of the preservation of moral and spiritual values, in a way that might not otherwise be possible."

# looking ahead

presents . . .

## A NATIONAL PLANNING ASSOCIATION POLL ON

### COMPENSATION OF TOP EXECUTIVES OF THE FEDERAL GOVERNMENT

ARE TOP EXECUTIVES in the Federal Government properly paid in relation to their responsibilities? Should they receive at least as much as executives performing similar services in private life, and more or less than members of Congress?

These are among the questions contained in an opinion survey conducted last month among the 800 members of NPA's board of trustees, standing committees, and National Council. Together these groups comprise a cross section of leaders from the fields of agriculture, business, labor, and the professions, and from all parts of the country. Almost 60% responded to a mail questionnaire which was designed to obtain some opinions on the proper level of compensation for members of the Federal Executive Service.

By Federal Executive Service is meant the more than 1,500 top Federal executives exclusive of the foreign service. Compensation for these executives ranges from \$22,500 for the heads of the ten executive departments to \$14,800 for the chiefs of major bureaus. Of the 1,515 in this group 838 are political appointees and 677 are in the civil service. The top executive group includes the heads of Federal departments and executive agencies, members of independent boards and commissions, under-secretaries, assistant secretaries and general counsels of departments, chiefs of major bureaus, and the top administrative posts in the civil service.

The first question inquired: "On the whole, would you say executives of the Federal Government receive too little compensation, too much, or do they get just about the right amount?"

71% of the respondents thought that Federal executives receive too little compensation. Only four persons (1%) thought they received too much. 24% thought they received the right amount.

TABLE A Answers to Question 1

	Agric.	Bus.	Lab.	Prof.	Total
Too much .....	2%	1%	—	1%	1%
Too little .....	61	73	81%	63	71
Right amount .....	37	19	19	32	24
No answer .....	—	7	—	4	4

The next question asked: "What compensation (including fringe benefits) should executives of the Federal Government get as compared with executives performing comparable services in private life? Should compensation be greater for government executives, less, or about the same?"

The group was more evenly divided on this ques-

tion. The majority (55%) thought that Federal executives should be compensated the same as in private life. 30% thought they should receive less, and only 10% stated that they should receive a greater amount than in private life. Members of the professions responded somewhat differently, with only 5% recommending higher compensation than in private life.

TABLE B Answers to Question 2

	Agric.	Bus.	Lab.	Prof.	Total
Greater .....	9%	12%	17%	5%	10%
Less .....	37	27	15	36	30
Same .....	50	56	68	55	55
No answer .....	4	5	—	4	5

The third question concerned the caliber of executives in the Federal Government. It asked: "Regardless of the party in power, do you feel the Federal Government should have executives of greater competence than executives in private enterprise, lesser competence, or should they be about the same level of competence?"

The NPA group was almost equally divided between recommending greater competence or about the same level of competence, with about 48% in each category. Only two respondents (less than 1% of the total) thought such executives should have lesser competence. The response from the professions closely matched the total response. More of the business leaders (55%) favored the same level of competence, and a fewer number (40%), recommended greater competence. On the other hand, 68% of the labor representatives and 52% of the agricultural leaders voted for greater competence.

TABLE C Answers to Question 3

	Agric.	Bus.	Lab.	Prof.	Total
Greater competence .....	52%	40%	68%	48%	48%
Lesser competence .....	—	1	—	1	1
About the same .....	44	55	32	47	48
No answer .....	4	4	—	4	3

The fourth question was: "What compensation should the highest Federal executives immediately below the President (e.g., Cabinet members, Director of the F.B.I., Director of Central Intelligence, President of Export-Import Bank, Director of the Budget Bureau) receive in relation to the compensation for a member of Congress?"

A majority, 78%, said that these officials should

receive more than Senators and Representatives (\$22,500). A larger percentage of the labor (28%) and agricultural leaders (26%) thought that such Federal officers should get the same pay as Congressmen, as contrasted with 17% of the professional group and 11% of the business respondents.

Although the question was not asked, a number of respondents commented that they thought members of Congress are still underpaid. (In a number of reports NPA has recommended substantial increases in the compensation of members of the Congress.)

TABLE D Answers to Question 4

	Agric.	Bus.	Lab.	Prof.	Total
More	70%	82%	68%	79%	78%
Same	26	11	28	17	16
Less	2	1	2	2	2
No answer	2	6	2	2	4

The final question asked the group to list the salary which they thought would be "most appropriate" for five different Federal executive positions.

The current salaries of these positions were not mentioned, other than that they range from a top of \$22,500 to a low of \$14,800. The figures suggested by the respondents ranged from a low of \$10,000 to a high of \$100,000. In addition, a considerably larger percent of the respondents did not reply to this question. Whereas an average of 4% failed to reply to any of the first four questions, an average of 25% did not list specific salaries.

On the average, 52% of all respondents were in favor of salaries in excess of \$25,000 for all five positions listed. Less than 1% favored salaries under \$15,000.

In general, business respondents favored larger salaries than did the other groups, and labor leaders were the most conservative of the four groups in amounts of salaries recommended. Of those recommending salaries in excess of \$50,000 the business respondents led all groups.

Following are the positions for which salary suggestions were asked:

a. Head of an Executive Department (such as the Department of the Treasury)—Current Salary: \$22,500.

76% favored salaries above \$25,000. The largest single category (28% of the respondents) favored \$50,000 and over. 38% of the business respondents were in this category and 15% of the labor group.

b. Administrative Assistant to the President—Current salary: \$15,000-\$20,000.

61% suggested \$25,000 or above. A larger number of the business leaders (67%) named this amount.

c. Member of a Federal Board or Commission—Current salary: \$15,000.

67% listed salaries of \$20,000 or above for this position. The two figures named most frequently were \$20,000-\$25,000, by 23% of the respondents and \$25,000-\$30,000 by 24%.

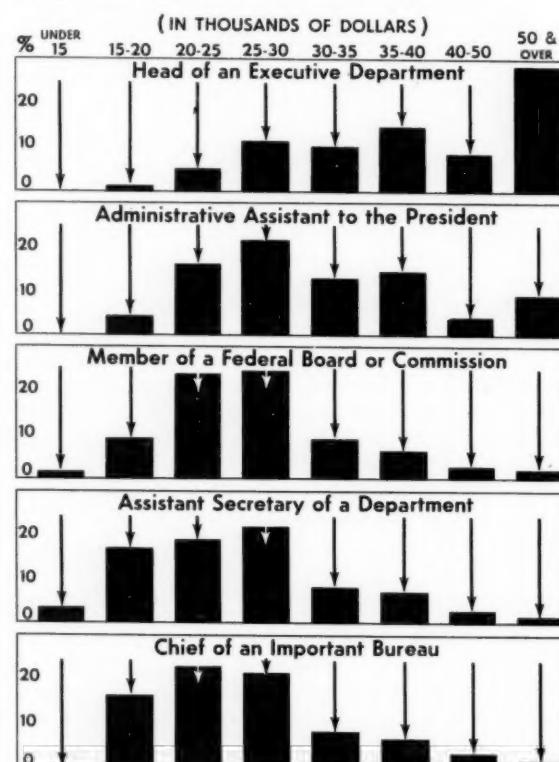
d. Assistant Secretary of a Department—Current salary: \$15,000.

59% were in favor of \$20,000 or more. 52% of the

agriculture group and 26% of labor suggested the \$15,000-\$20,000 range.

e. Chief of an Important Bureau (such as the Bureau of the Budget)—Current salary: \$14,800.

63% suggested the \$20,000 and over category. 21% of all respondents favored \$25,000-\$30,000, while 29% of the professional group and 33% of the agriculture group listed the \$20,000-\$25,000 range.



#### THE SAMPLE

Of the 800 questionnaires mailed following is the breakdown among the four major economic groups, and a comparison with the 472 replies.

	Total Sample	Total Replies
Agriculture	11%	13%
Business	47	46
Labor	15	11
Professions	27	30
Total	100%	100%

The major geographic regions were represented as follows:

	Total Sample	Total Replies
West	14%	13%
North Central	27	27
Northeast	33	30
South	26	30
Total	100%	100%

*NOTE: Additional single copies of this issue of LOOKING AHEAD are available without charge from the National Planning Association, 1606 New Hampshire Ave., N. W., Washington 9, D. C.*

## Foreign Investment in Underdeveloped Countries

FOR THE PURPOSE of stimulating foreign investment in underdeveloped countries, the governments of both capital-exporting and capital-importing states have sought to reduce the impediment of double taxation on income earned abroad and to provide other tax incentives to private investment capital. A summary of some of the tax devices employed has been prepared by the Secretary General in a memorandum for the UN Economic and Social Council published May 23, 1956.

Though recognizing the desirability of tax concessions to promote increased flow of development capital, only a few countries, the report states, accept the extreme principle of confining taxation to domestic income, and most claim jurisdiction over some or all foreign-earned income of their nationals. Loss of revenue, impairment of tax equity, uncertainty of effectiveness, and scarcity of investment funds have been considerations militating against relinquishment of tax rights by capital-exporting countries.

However, economic exigencies of the last decade have prompted governments to sign an increasing number of bilateral agreements providing specific tax relief to investors, and through unilateral tax credit on foreign paid taxes and other measures, double taxation has been reduced or its effects mitigated. About 350 bilateral agreements on this problem are currently in operation according to the memorandum.

Measures, the memorandum notes, employed by capital-exporting countries to provide tax relief include encouragement of the foreign subsidiary whose earnings are not taxed by the country of the parent company--some countries exempting profits of such subsidiaries when returned as dividends; tax concessions designed to carry out specific economic policies such as reduction of taxes on Western Hemisphere Trade Corporations by the United States. A plan endorsed by the Secretary of the Treasury and the President would permit tax credit not only for taxes actually paid by an investor to the capital-importing country, but also for taxes which were remitted to the investor by the foreign state as a special investment incentive.

TAX INCENTIVES noted by the report in capital-importing countries include exemp-

tions or reduced taxes for pioneer industries; reductions or exemptions from indirect taxes such as sales and turnover taxes, land and property taxes, export and import duties; and, tax incentives for reinvestment or retention of profits in the underdeveloped country.

Governments of capital-importing countries, the memorandum states, have been motivated by "the desire to protect their limited tax resources--to which foreign investors are often important contributors--, and the need to avoid popular disaffection from their developing income taxes because of discrimination in favour of large--and especially foreign--income earners. They have therefore sought to limit their tax concessions to enterprises most likely to respond and to make substantial contributions to their economic development programmes..."

A number of country studies are being made for the UN--the most recently published "United States Income Taxation of Private United States Investment in Latin America." The memorandum also notes the country studies to be published as part of the World Tax Series which the International Programme in Taxation of Harvard Law School is undertaking in cooperation with the UN Secretariat.

(*International Tax Problems. Taxation in Capital-Exporting and Capital-Importing Countries of Foreign Private Investment.*" E/2865 May 23, 1956, 19 pp.)

## Toward the Well-Being of Children

MARSHALL FIELD, a member of NPA's board of trustees, has announced the formation of Marshall Field Awards, Inc., a non-profit organization "to recognize and reward fundamental and imaginative contributions to the well-being of children."

Six to nine annual awards will be made to individuals, organizations, and communities for work in the fields of education, physical and mental development, social welfare, and communications.

Mr. Field, noting the inadequate investment of money and manpower in the professional fields serving children, voiced the hope that the awards would "focus public attention on children's needs and on the areas in which improved services are urgently required," and that they would "call attention to constructive programs which set an example for others to follow."

## Better Technical Cooperation

STEPS WHICH CAN be taken to improve our technical cooperation programs—private and public, national and international—are described in over 100 recommendations of the NPA Special Policy Committee on Technical Cooperation made in a report which summarizes the results of a three-year study of technical cooperation in Latin America.

The NPA Committee which was composed of 26 U. S. and Latin American leaders from agriculture, business, education, health, labor, professional, and religious groups found technical cooperation to be an effective instrument for the promotion of international welfare, yielding high reward for a relatively small investment of money, men, and effort. It urged that an improved program, increased from year to year, be accepted as a long-range element of U. S. policy.

Laird Bell, a senior partner of Bell, Boyd, Marshall & Lloyd in Chicago and NPA trustee, is chairman of the Special Policy Committee. Theodore W. Schultz of the University of Chicago and also a trustee, is director of research. ("Technical Cooperation in Latin America—Recommendations for the Future." NPA Special Policy Committee on Technical Cooperation. From NPA: June 1956. xii, 192 pp. \$2.50)

## High Temperature Symposium

SOME OF THE MOST important frontier technological problems concern the attainment of high temperatures and the reaction of materials to intense heat. From June 25-27, the University of California and the Stanford Research Institute jointly sponsored a symposium at Berkeley on progress in the field of high temperature research.

The three-day discussions dealt with methods of reaching high temperatures—solar, arc, and flame images, electrical heat, and chemical and nuclear processes; structures and properties of materials required for containing high temperatures; and the chemical reactions and processes occurring at extreme temperatures.

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